RHODORA, Vol. 103, No. 913, pp. 47–70, 2001

CONSERVATION STATUS OF SAINT JOHN RIVER VALLEY HARDWOOD FOREST IN WESTERN NEW BRUNSWICK

ANDREW MACDOUGALL[1]

Nature Trust of New Brunswick, P.O. Box 603 Station A,
Fredericton, NB, Canada, E3B 5A6
[1]Current Address: Department of Botany,
University of British Columbia, Vancouver, BC, Canada, V6T 1Z4
e-mail: asmacdougall@sprint.ca

ABSTRACT. Saint John River Valley Hardwood Forest (SJRHF) is a regionally threatened northern disjunct plant assemblage of the central St. John River Valley and associated tributaries of southwestern New Brunswick and northeastern Maine. Two centuries of land clearance have reduced this assemblage to less than 1% of its original extent. Remaining stands, especially of more mature trees, support 31 regionally rare vascular plant taxa and are at risk due to increased cutting. Assessment of the effect of recent disturbance on SJRHF has been hampered by limited distributional information; past surveys were wide-ranging but nonsystematic. This study describes results of a systematic habitat-based survey for SJRHF remnants across 2000 km^2 of western New Brunswick. One hundred and twenty one stands were assessed for the presence of rare vascular plant taxa and disturbance. Fifty-four previously unknown stations with one or more rare SJRHF taxa were identified. Two new taxa were discovered for the province and one provincially extirpated taxon was re-located. One hundred and fifteen of 121 stands showed evidence of tree harvest. Within the last two decades, 46% of the surveyed sites had been fully or partially clearcut or converted to potato fields. Ongoing stand loss suggests that conservation measures are required to maintain remnant assemblages. In situations where reserve formation is not possible, occurrence of SJRHF herbs, including rare taxa, in previously select-cut stands indicates that modified low-intensity harvest strategies may not be incompatible with their persistence.

Key Words: Saint John River Valley Hardwood Forest, New Brunswick, Maine, deciduous forest, rare vascular plant taxa, conservation

Saint John River Valley Hardwood Forest (SJRHF) is a regionally threatened northern disjunct deciduous forest assemblage of the central St. John River Valley and associated tributaries of southwestern New Brunswick and eastern Aroostook County, Maine (Figure 1). The floral composition of SJRHF resembles broadleaf forests of north-central New England, eastern Ontario, and the central St. Lawrence River Valley of Quebec, but the

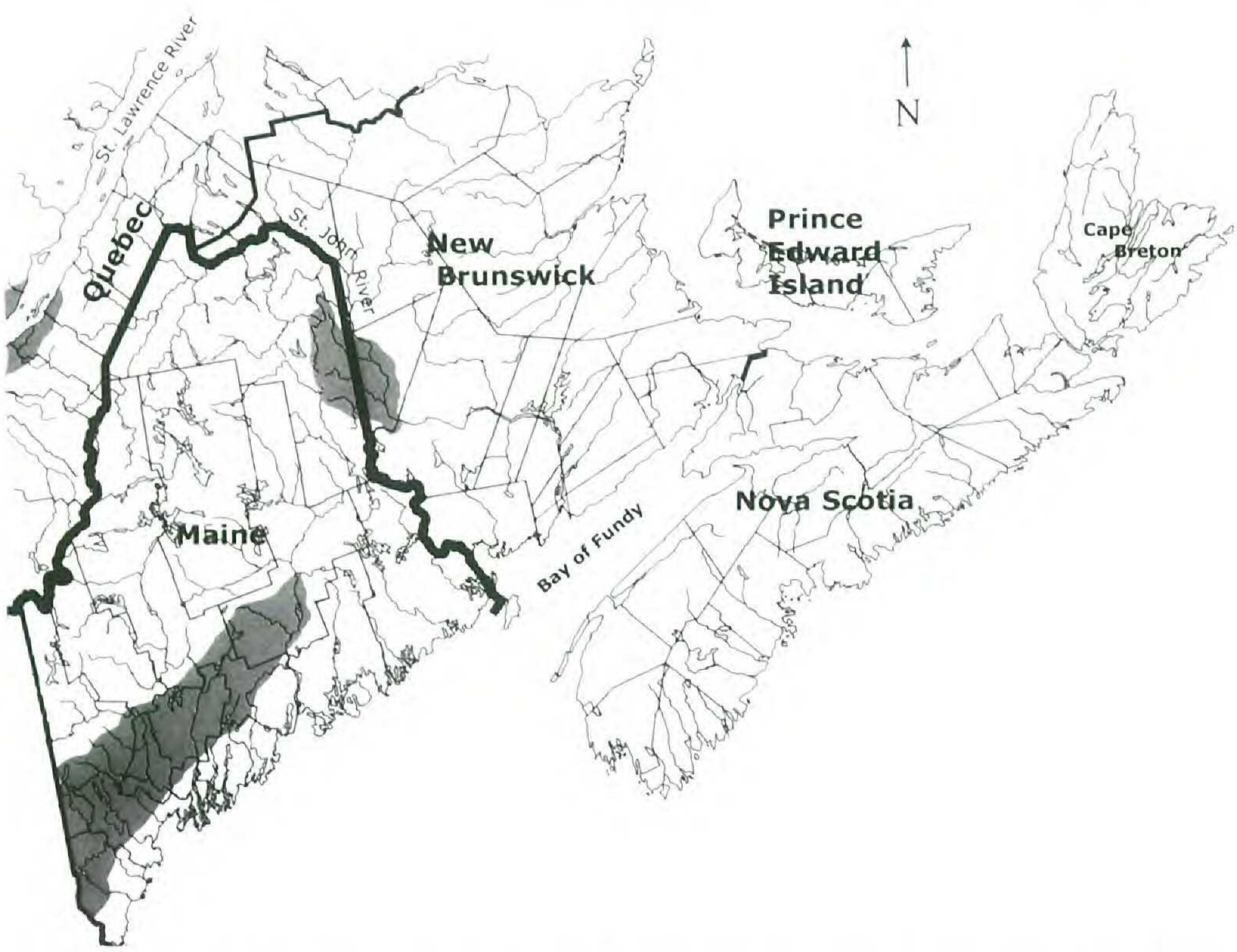

Figure 1. Major concentrations of eastern deciduous forest vascular flora (shaded) within Maine, southeastern Quebec, and the Maritime Provinces of eastern Canada. Maine and Quebec distributions extrapolated from Eastman (1981) and McMahon (1990), and from Rousseau (1974), respectively.

assemblage is isolated from these areas by 150 km or more. Associated with the enriched calcareous soils and moderate climate of the central St. John River Valley, SJRHF has been subject to extensive land clearance since the onset of European settlement in the early 1800s. Saint John River Valley Hardwood Forest presently covers less than 1% of the land base believed to have once supported this assemblage (MacDougall and Loo 1998). It provides habitat for 31 vascular plant taxa considered rare or threatened within New Brunswick, Maine, the Maritime Provinces, or the Gulf of St. Lawrence region in general (Gawler et al. 1996; Hinds 1983; New Brunswick Committee on Endangered Species 1995; Pronych and Wilson 1993). Recent increased logging and agricultural land clearance have led to concerns regarding the persistence of SJRHF in New Brunswick, though assessment of the distribution and conservation status of remnant patches has been limited by nonsystematic past survey efforts. Of particular concern are the ranges of rare SJRHF vascular plant species, and the degree to which increased disturbance has affected SJRHF remnants.

This paper presents results of a systematic habitat-based survey for SJRHF stands across approximately 2000 km^2 of southwestern New Brunswick. The objectives are to: 1) describe the distribution of remnant SJRHF stands, 2) describe the rare vascular plant species composition and disturbance history of the remnants, and 3) discuss the implications of these findings for future conservation management efforts.

STUDY AREA

General description. Saint John River Valley Hardwood Forest is a deciduous forest assemblage dominated by *Acer saccharum* Marsh, *Fagus grandifolia* Ehrh., *Fraxinus americana* L., and *Betula alleghaniensis* Britton, with *Ostrya virginiana* (P. Mill.) K. Koch, *Juglans cinerea* L., *Tilia americana* L., *Ulmus americana* L., and *Tsuga canadensis* (L.) Carriere as secondary components (MacDougall and Loo 1998). This assemblage occurs near the periphery of the eastern deciduous forest formation described by Braun (1950) and possesses the most northeasterly occurring concentration of southern-affinity vascular plant taxa within this formation. It is also found along a gradient of declining deciduous forest floral diversity that runs to the north and east of North America. This is made evident by the absence of taxa such as *Carya ovata* (P. Mill.) K. Koch, *Dicentra canadensis*, and *Phegopteris hexagonoptera* (Michx.) Fee that are characteristic of broadleaf forests to the south, and which extend into Ontario and Quebec. The relative abundance of *F. americana,* plus the presence of *J. cinerea, T. americana,* and understory species such as *Galearis spectabilis* and *Phryma leptostachya* distinguishes SJRHF from other hardwood forest types found in northern Maine and the Maritime Provinces [Note: The butternut bark canker (*Sirococcus clavigignenti-juglandacearum*) has yet to seriously affect New Brunswick *J. cinerea* populations, though several possibly infected trees were observed in the central St. John River Valley in 1997–98 (K. Harrison, Canadian Forest Service, pers. comm.)].

Environmental conditions of the central St. John River Valley. Saint John River Valley Hardwood Forest is associated with the rich and well-drained calcareous soils and relatively moderate climate that characterize the central St. John River Valley and associated tributary valleys. The extent of the calcareous soils generally defines the regional boundaries across New Brunswick and Maine (McMahon 1990; New Brunswick Department of Natural Resources and Energy 1996). In New Brunswick, two edaphic units predominate, and are the most fertile and intensively farmed soils in the province (Colpitts et al. 1995; New Brunswick Department of Natural Resources and Energy 1996). The Caribou Soil Unit is a finely textured and fast-draining glacial till derived from Ordovician argillaceous parent material. It is the richer of the two soil groups and occurs mostly to the west of the St. John River extending into Maine. The Carleton Soil Unit is a fine-textured compact glacial till derived from Silurian calcareous sandstone and is found on the lower reaches of the central St. John River Valley, especially on the east side of the river between Hartland and Florenceville, New Brunswick.

Topographically, the region is dissected by the Kintore Hills, a narrow, rugged, noncalcareous upland that cuts across the St. John River Valley in an east-west direction just below the juncture of the Aroostook and St. John Rivers (Figure 2). To the south of the Kintore Hills, the terrain is flat to gently rolling with elevations generally below 200 m. Upriver, the terrain is more undulating; areas below 200 m occur mostly in proximity to the Aroostook and St. John Rivers. To the east and the southeast of the central St. John River Valley, the regional boundaries are defined by noncalcareous metamorphic or granitic uplands (Loucks 1961; New Brunswick Department of Natural Resources and Energy 1996).

The climate of the central St. John River Valley is warmer and drier than adjacent regions of Maine and New Brunswick (Deevey 1951; McMahon 1990), with slightly higher average summer temperatures (Millette and Langmaid 1964), a longer frost-free period (80 to 120 days; Hinds 1980), and annual precipitation around 1050 mm (New Brunswick Department of Natural Resources and Energy 1996).

Post-glacial origins. The origins of SJRHF lie in the vegetation changes that occurred in northeastern North America following glacial retreat approximately 13,000 YBP. Saint John River Valley Hardwood Forest is assumed to be a relic disjunct as-

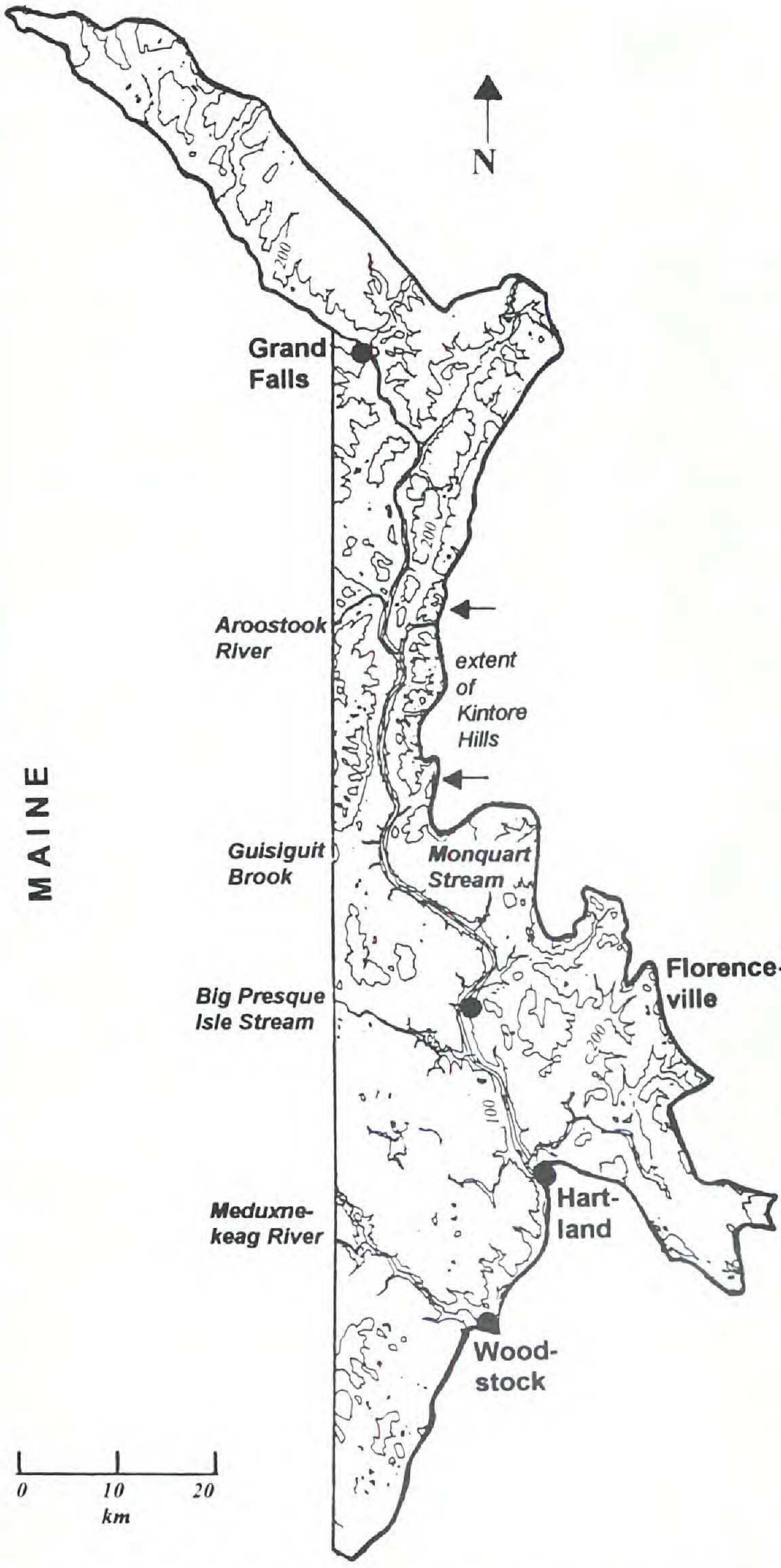

Figure 2. Study area boundaries within the central St. John River Valley of New Brunswick, as defined by New Brunswick Department of Natural Resources and Energy (1996). Contour intervals are 100 m.

semblage (*sensu* Kellman 1980; Raup 1937), a remnant of a previously wide-ranging broadleaf forest that retreated south from the Maritime Provinces due to climatic change, but was locally maintained due to favorable habitat conditions. Supporting evidence comes from two sources: tree pollen data and extrapolations of past distribution based on existing herb taxa occurrence patterns, including extirpation information.

Tree pollen data indicate that thermophilous hardwood forest was previously more abundant in northern New England and the Maritime Provinces, peaking between approximately 5100–3000 YBP (Anderson et al. 1986; Green 1987; Mott 1975a, 1975b). The northward movement of broadleaf forest was driven by the warmer and mostly drier climate that characterized northeastern North America during the early and mid-Holocene (Davis 1976; Davis et al. 1980; Prentice et al. 1991). Mott (1975a, 1975b) speculated that, at the time of peak abundance, New Brunswick's hardwood forest resembled present-day SJRHF, with high levels of *Fraxinus, Acer, Betula, Fagus,* and *Ulmus.* Following 3000 YBP, climatic degradation led to a decline of broadleaf tree species and an increase in *Picea* spp. and *Abies balsamea* (L.) P. Mill.

Present-day occurrence patterns of mesic herbs in the Maritime Provinces suggest that many were once more widely distributed. Isolated stations of southern-affinity herbs are scattered across the region—SJRHF is the most extensive and species-rich, but sites with some SJRHF elements also occur in northern New Brunswick's Restigouche River Valley (Cooney 1832; Hay 1896; Hinds 1983,1986), the lower St. John River Valley of New Brunswick (Hinds 1983, 1986; MacDougall et al. 1998), and several areas in Nova Scotia including Cape Breton (Fernald 1921, 1922; Nicholls 1918; Pronych and Wilson 1993; Robinson 1903; Zinck 1998). Because many broadleaf forest herbs are notoriously poor dispersers (Bierzychudek 1982; Cain et al. 1998; Matlack 1994), formation of these isolates by long-distance migration seems unlikely: the distances separating isolates are too great, the numbers of taxa in these areas are too large to have been established by low frequency long-distance dispersal events, and the areas are separated by nondeciduous forest habitat within which mesic herbs rarely or never establish. Instead, species likely migrated into the region in association with the more widely ranging deciduous forest of the mid-Holocene. As this forest contracted, mesic herb populations persisted in local areas with rich soils, either narrow alluvial bottomlands or sites with calcareous parent material. One area in the Maritime Provinces with few SJRHF taxa is Prince Edward Island. Prince Edward Island became isolated from the New Brunswick and Nova Scotia mainland between 5000–3000 YBP due to ocean level increase (Bousfield and Thomas 1975; Kranck 1972). Many northward-migrating plants may not have reached the Northumberland Strait area until after the corridor became submerged, though the intense level of habitat conversion on Prince Edward Island that followed settlement (Erskine 1985) could also explain floral impoverishment.

Extirpation evidence also suggests that mesic herbs were previously more prevalent. *Cryptotaenia canadensis*, a deciduous forest species found throughout most of central and eastern North America (Fernald 1950), was formerly known from several stations in New Brunswick and Maine but has not been seen in either jurisdiction since the early- to mid-1900s (Eastman 1981; Hinds 1983). Similarly, *Trillium grandiflorum* (Michx.) Salisb. has not been seen in Maine since 1926 (Campbell et al. 1995), and an old report apparently exists for western New Brunswick (H. Hinds, pers. comm.).There are also reports of *Betula lenta* L. (Braun 1950; Cooney 1832; Halliday 1937; Perley 1847), *Carpinus caroliniana* Walter (Fernow et al. 1912; Michaux 1808; Perley 1847; Speck and Dexter 1952), and *Ulmus rubra* Muhl. (Perley 1847; Speck and Dexter 1952) in the central St. John Valley or the Maritime Provinces in general, though none has ever been formally collected. Although these records could easily be the result of identification errors or misapplication of common names (e.g., "black birch", the common name of *Betula lenta*, was often used to describe *B. alleghaniensis* in 18th century New Brunswick survey records; Lutz 1997), their occurrence is plausible due to the close proximity of their present-day northern range limits in central or southern Maine (Burns and Honkala 1990). The anecdotal nature of this extirpation evidence could reflect, in part, the period when these species disappeared from the region. Fertile habitats were usually subject to immediate clearing by settlers. Taxa that were already rare at the time of settlement may have been eliminated before botanical surveys commenced in the mid- to late-1800s.

Settlement history. The settlement of western New Brunswick and eastern Aroostook County by Europeans did not begin until the early 1800s. Before this time, the Malecite Indians occupied the St. John River Valley for at least two millennia, using the river and associated tributaries as travel corridors to access coastal wintering areas and interior hunting grounds (Ganong 1899). The Malecite established few permanent settlements and practiced agriculture on a very limited basis compared to groups in central New England (e.g., Cronon 1983), and thus are believed to have had little impact on the forest.

In the early 19th century, large numbers of settlers began entering the central St. John River Valley from the lower St. John River Valley and from central Maine; land grants along the river and in the backcountry were quickly filled. At that time, the region was called "the garden of Maine" due to its fertile soils (Bailey 1894). It was estimated that it took only 50 years, ending in the 1860s, for the area to be converted from "dark wilderness" to a pastoral landscape (Bailey 1894). During the period of peak settlement, which lasted for most of the 19th century, the area was dominated by farms and small communities. Patches of forest persisted mostly as woodlots subject to selective cutting and may have served as the only refuges for SJRHF flora.

Following the turn of the century, rural land abandonment began in the central St. John River Valley, mirroring trends observed elsewhere in eastern North America as populations shifted to urban centers (Foster et al. 1998; Matlack 1997). Many farms, especially away from the rivers, reverted back to forest. Remnant SJRHF stands that survived the 1800s are thought to have remained stable for most of the 20th century. Recent increases in the demand for hardwood, combined with improved harvest capabilities, have led to increased cutting. Given that many of the region's second growth forests have not fully developed and possess low percentages of tolerant hardwood tree species, it is the older stands supporting remnant SJRHF species that are most at risk.

Early botanical explorations and forest classifications. The botanical significance of the St. John River Valley and associated tributaries was recognized soon after settlement. In addition to the hardwood flora, botanists were also drawn to the calcareous fens, poorly drained *Thuja occidentalis* L. forests, and rocky calcareous shorelines of the region that hosted numerous rare taxa [e.g., *Astragalus alpinus* L. var. *brunetianus* Fernald and *Polygala senega* L. along shorelines; *Carex sterilis* Willd., *Salix candida* Willd., and *Valeriana uliginosa* (Torr. & Gray) Rydb. in fens and swamp forest]. George Goodale, curator of botany for the Portland Society of Natural History, visited eastern Aroostook County in the 1860s. He noted the presence of southern-affinity taxa and commented on the unique character of the region relative to New England in general (Goodale 1861, 1862). During the next several decades, numerous botanical forays were made on both sides of the border, expanding the list of species and confirming the significance of the area (e.g., Fernald and Wiegand 1910; Hay 1883; St. John 1929). Species lists compiled during this period for New Brunswick (Fowler 1885; Hay 1901; Hay et al. 1882, 1884) contain most of the SJRHF taxa found today. These lists have served as valuable references for re-locating populations of rare species and assessing distribution changes.

The significance of SJRHF was also recognized in regional vegetation classifications for New England and the Maritime Provinces. Though small in area and disjunct in distribution, SJRHF was classified by Hawley and Hawes (1912) as part of the northern hardwood association typical of southern Maine, New Hampshire, Vermont, western Massachusetts, and northern New York. Braun (1950) followed this classification. Loucks (1961) similarly recognized the distinct character of this forest relative to surrounding areas, distinguishing it as a separate forest region for the Maritime Provinces.

MATERIALS AND METHODS

Identification of potential sites. Potential SJRHF sites in western New Brunswick were identified using a fine-scale habitat-based search procedure conducted on a Geographical Information System (GIS). The procedure focused on the selection of locations with a high probability of hosting rare vascular flora. Sites identified by the GIS method possessed a combination of spatially referenced environmental data layers (e.g., forest cover, soil fertility) that together best described the habitat conditions associated with SJRHF rarities: mature deciduous forest stands on well-drained calcareous soils. This habitat description was based on existing SJRHF occurrence observations in New Brunswick, combined with studies in eastern North America that demonstrated a paucity of woodland herbs in immature and heavily disturbed deciduous forest stands (Matlack 1994; Meier et al. 1995; Whitney and Foster 1988). The use of this site identification procedure was necessary due to the extensive area of the river valley (2000 km^2) and the random and visually indiscrete distribution of mature stands embedded within a landscape of farms, settlements, and regenerating forest. By directing ground surveys to mature deciduous forest stands, large areas considered unsuitable for rare SJRHF vascular flora in terms of habitat (e.g., bogs) or disturbance (e.g., old field *Populus* spp.–*Abies balsamea* forest) were avoided. Site identification was not conducted in Maine due to time constraints and the perception that the hardwood forests of Aroostook County had undergone more intensive and widespread disturbance than in New Brunswick (S. Rooney, pers. comm.). Only a few scattered SJRHF stations are known from Aroostook County, and they contain just over half of the rare taxa found in New Brunswick.

The GIS search method for identifying potential sites consisted of three sequential steps. The first two steps—identifying the regional study area boundary and selecting well-drained calcareous soil units—employed a previously established multi-level Ecological Land Classification (ELC) developed for the province of New Brunswick (New Brunswick Department of Natural Resources and Energy 1996; Zelazny et al. 1997). The ELC was derived using combinations of abiotic and vegetational data layers across a range of spatial resolutions, including fine-scale edaphic and topographic habitat variables targeted by this study. The third step in the identification process involved stand-level photo-interpreted data describing canopy composition and age class.

The study area boundary was defined by the ELC district-level (1:250,000) classification delineated using geomorphological and topographical information. This boundary followed the distribution of calcareous parent material within the St. John River Valley, running from below Woodstock, New Brunswick, to St. Leonard, New Brunswick, north of Grand Falls (Figure 2). The international boundary defined the western limit. All previously known SJRHF sites but one occurred in this district.

The second step employed ELC site-level (1:20,000) designations delineated using information on soil fertility, soil drainage, elevation, and slope, and supplemented with forest cover data.

Site units with well-drained and calcareous-based soils on all slope and elevation classes were selected. These units covered 51% of the entire district within the central St. John River Valley; the remaining area included poorly drained calcareous wetlands, mostly dominated by *Thuja occidentalis* forest, and noncalcareous sites of the Kintore Hills. All previously known SJRHF sites were found on the selected units.

The final step involved stand-level, photo-interpreted forest cover data. These data, described by New Brunswick Department of Natural Resources and Energy from 1981 photos (1:12,500 resolution), identified dominant canopy composition and age-class in forest stands. Stands were selected for "100% tolerant hardwood" of the "mature" (> 80 years) and "overmature" (> 120 years) age classes occurring on the three targeted site-level units. Seven of the 15 previously known SJRHF sites were not captured by this procedure; all had been classified from aerial photographs as "100% tolerant hardwood", but in the "immature" age class (50–80 years). This suggested that these sites were either incorrectly classified "mature" stands, or that the assumption that rare SJRHF plant assemblages only occurred in older growth stands was incorrect.

The end product of this GIS-based search, incorporating the three data layers and covering all of New Brunswick's central St. John River Valley, was 108 small (mean = 11.3 ha; range 0.82–112.3 ha) and isolated stands covering 0.8% of the study region. They were the basis for all initial field work.

Field assessment. The GIS-identified stands, plus the previously known SJRHF sites not captured by the procedure, were surveyed by either one of two field crews between May 21–July 1, 1997. This period was selected as the optimal time for viewing spring ephemeral plant taxa in New Brunswick. The survey procedure focused on the location and abundance of targeted rare vascular plant taxa (Table 1). Targeted flora were SJRHF taxa listed as provincially uncommon, rare, or very rare by Hinds (1983, 1986), plus deciduous forest taxa known from north-central and northern Maine (*Dicentra canadensis* and *Panax quinquefolius*, respectively) but not recorded in New Brunswick.

Each stand was surveyed to: 1) generally characterize tree and understory plant composition and 2) locate rare vascular plants. Formal transect and plot sampling were not conducted due to

Table 1. Rare vascular plant taxa of Saint John River Valley Hardwood Forest. X = uncommon, rare, or very rare in New Brunswick (NB; Hinds 1983, 1986), rare or very rare in Maine (Haines and Vining 1998), rare in Nova Scotia (NS; Pronych and Wilson 1993; Zinck 1998). – = does not occur in the province; ** = occurred historically; may be extirpated; + = not listed as rare. "Prev." is the number of records previously known from New Brunswick (Connell Memorial Herbarium UNB). "New" is the number of new records found by this study. Nomenclature follows Campbell et al. 1995. # = possibly extirpated from Prince Edward Island (Erskine 1985); ## = rare in Prince Edward Island (Erskine 1985).

Taxon	Status			Prev.	New
	NB	Maine	NS		
Adiantum pedatum L. #	X	+	X	9	19
Allium tricoccum Aiton	X	X	X	9	0
Asarum canadense L.	X	X	–	15	21
Botrychium lanceolatum (S. G. Gmel.) Angstr. subsp. *angustisegmentum* Pease & A. H. Moore	X	+	X	7	2
Cardamine concatenata (Michx.) Sw.	X	X	–	3	1
Carex cephaloidea (Dewey) Dewey	X	+	–	2	1
Carex hirtifolia Mack.	X	X	+	4	2
Carex plantaginea Lam.	X	+	**	6	12
Carex sprengelii Dewey *ex* Spreng.	X	X	–	9	2
Caulophyllum thalictroides (L.) Michx.	X	+	X	13	9
Cryptotaenia canadensis (L.) DC.	**	**	–	–	0
Cynoglossum virginianum L. var. *boreale* (Fernald) Cooperrider	X	X	X	3	1
Cypripedium pubescens Willd. ##	X	+	X	29	20
Desmodium glutinosum (Muhl. *ex* Willd.) A. Wood	X	+	X	–	1
Dicentra canadensis (Goldie) Walp.	–	X	–	0	0
Dirca palustris L.	X	+	X	6	7
Dryopteris clintoniana (D. C. Eat.) Dowell	X	X	–	1	1
Dryopteris goldiana (Hooker *ex* Goldie) A. Gray	X	X	–	5	13
Dryopteris clintoniana × *goldiana*	X?	X?	–	0	1
Dryopteris × *dowellii* (Farwell) Wherry	X?	X?	–	0	1
Elymus hystrix L.	X	X	X	3	1
Festuca subverticillata (Pers.) E. B. Alexeev	X	X	X	2	4
Galearis spectabilis (L.) Raf.	X	X	–	7	4
Hepatica nobilis P. Mill. var. *obtusa* (Pursh) Steyerm.	X	+	X	11	1
Impatiens pallida Nutt.	X	X	+	2	0
Panax quinquefolius L.	–	X	–	0	0
Phryma leptostachya L.	X	**	–	8	7
Rubus occidentalis L.	X	+	–	8	8

Table 1. Continued.

Taxon	Status			Prev.	New
	NB	Maine	NS		
Sanicula odorata (Raf.) Pryer & Phillippe	X	X	+	4	1
Sanicula trifoliata E. P. Bicknell	X	X	–	3	3
Triosteum aurantiacum E. P. Bicknell	X	X	X	6	1
Viola canadensis L.	X	X	X	4	3

their potential insensitivity to rare plant distribution (H. Hinds, pers. comm.). Instead, stands were first walked in their entirety; all encountered tree and understory species were recorded and estimated for stand abundance. Aerial photographs assisted in determining stand boundaries and in locating stream depressions and disturbance features (e.g., old trails, sharp changes in canopy architecture) not readily apparent from the ground. Once the stand had been walked, search effort focused on habitat features specifically associated with the presence of rare SJRHF taxa, especially groundwater seepage zones, micro-topographical depressions, exposed limestone outcrops, and stream-side alluvial formations. Epiphytic moss and liverwort taxa were informally surveyed in 53 stands [B. Bagnell (B & B Botanical, St. John, New Brunswick), unpubl.], representing the most widespread survey of the bryophyte flora for this region of New Brunswick. Disturbance history was assessed based on the presence of old roads and trails, stumps, fences, or stone piles within the stand, plus evidence of recent disturbance subsequent to the 1981 aerial photos. Stand structure was informally described to corroborate the photo-interpreted age class designations (e.g., did a "mature" stand possess small and uniformly sized trees more characteristic of young regenerating stands?). After July 1, some of the earliest surveyed sites were revisited to search for late-emerging species (e.g., *Impatiens pallida*).

Results from the initial survey period indicated that the Meduxnekeag River watershed possessed the greatest concentration of SJRHF sites with the most diverse floral assemblages compared to all other areas. In addition, all seven previously known SJRHF sites identified as "immature" occurred in this watershed. To determine if other stands classified as "immature" hosted rare assemblages in this area, the GIS-site identification procedure was used again. Additional stands were selected using stand size (>

10 ha), canopy composition ("100% tolerant hardwood"), and age class ("immature") on well-drained calcareous site units. Six sites were identified and surveyed.

RESULTS

One hundred and twenty one sites were surveyed within New Brunswick's central St. John River Valley, combining GIS-identified sites with previously known sites and additional stands identified within the Meduxnekeag River watershed. Four stands were not assessed due to incorrect photo-interpretation of stand composition (i.e., not "tolerant hardwood"). Access to three stands was denied by the land owner.

Forty-nine percent of the previously unsurveyed sites, including the six Meduxnekeag River sites, were considered to be SJRHF stands. An SJRHF stand was defined as a tolerant hardwood-dominated forest with a species-rich herb community that included one or more rare vascular plant taxa. This definition distinguished SJRHF from GIS-identified tolerant hardwood stands that lacked both common and rare SJRHF herb taxa due to disturbance, and from GIS-identified stands that were obviously mature but lacked SJRHF herb taxa due to site conditions. This latter distinction applied mostly to hardwood stands in the north where climate apparently limits SJRHF floral establishment.

Within the surveyed SJRHF stands, each targeted taxon was observed at least once except *Impatiens pallida* (Table 1). The most frequently observed rare species were *Asarum canadense* (21 new stations), *Cypripedium pubescens* (20 new stations), *Adiantum pedatum* (19 new stations), *Dryopteris goldiana* (13 new stations), *Carex plantaginea* (12 new stations), and *Caulophyllum thalictroides* (9 new stations). Several taxa were very infrequent, occurring in a small number of stands with populations typically fewer than 10 individuals (*Galearis spectabilis, Sanicula odorata, Dryopteris clintoniana, Cardamine concatenata*). Two fern hybrids, *D.* × *dowellii* and *D. clintoniana* × *goldiana* were recorded (J. Goltz) for the first time in the province. *Desmodium glutinosum,* not seen in New Brunswick since 1899 and classified as extirpated (New Brunswick Committee on Endangered Species 1995), was rediscovered on a calcareous shoreline (G. Bishop and B. Bagnell) immediately adjacent to a stand on the Meduxnekeag River.

Distribution of targeted SJRHF flora was concentrated in the southern half of the central St. John River Valley between Woodstock and Florenceville. The Meduxnekeag River Valley contained the largest number of stations (15) with one or more populations of all targeted rare taxa that were observed. Other watersheds of significance were Guisiguit Brook (ten stations) and Big Presque Isle Stream (six stations). Monquart Stream (seven stations) was the only watershed on the east side of the St. John River with multiple stations. To the north, the abundance and diversity of SJRHF taxa quickly diminished. *Tilia americana* was not recorded upriver from Hartland, New Brunswick. Most taxa reached their northern limit at the downriver edge of the Kintore Hills. North of this upland formation, only six rare taxa were observed; three of these were limited to one station. At Grand Falls, near the northern extent of the study area, most SJRHF species no longer occurred, including *Fraxinus americana* and *Ostrya virginiana.* To the south, downriver from Woodstock, surveyed stands were also less diverse; only four rare taxa were recorded.

A sharp contrast in the within-stand distribution of SJRHF ground flora was observed between seep and non-seep areas. Rare flora were usually clustered in moist microsites, even if these features covered only a small percentage of the total stand area. Dominant seep flora included combinations of *Deparia acrostichoides* (Sw.) M. Kato, *Matteuccia struthiopteris* (L.) Todaro var. *pensylvanica* (Willd.) Morton, *Adiantum pedatum,* and occasional *Dryopteris goldiana,* with *Erythronium americanum* Ker Gawl., *Viola pubescens* Aiton, *Sanguinaria canadensis* L., *Asarum canadense,* and *Arisaema triphyllum* (L.) Schott prevalent. *Juglans cinerea* and *Tilia americana* occurred primarily in these areas. In non-seep areas, dominant ground flora were *E. americanum, Maianthemum racemosa* (L.) Link, *Claytonia caroliniana* Michx., *Polystichum acrostichoides* (Michx.) Schott, *Trillium erectum* L., *Botrychium virginianum* (L.) Sw., and *Dicentra cucularia* (L.) Bernh. Large patches of *Taxus canadensis* Marshall were occasionally present.

One hundred and fifteen of the 121 surveyed stands showed direct evidence of human disturbance based on the presence of stumps, old extraction trails, or stone fences. At ten of these sites, the overstory had been completely removed since 1981 and the stands converted either to potato fields or clearcut; these were excluded from further analysis. Of the remaining stands, 73 of

111 showed evidence of logging within the last 16 years; 37% had been partially harvested. Three stands contained rock walls or split-rail fences within their understory, indicating that part of the stand had formerly been cultivated or pastured. No area of forest understory showing signs of past cultivation or pasturing possessed any rare floral elements.

DISCUSSION

Distribution patterns. Saint John River Hardwood Forest stands were found to be more numerous than originally thought but, unexpectedly, they did not occur throughout the study area. Stand distribution was concentrated below the Kintore Hill formation between Woodstock and Florenceville. Upriver, most vascular plant taxa became increasingly infrequent, or were absent, despite the persistence of the rich soils. The most likely primary cause of this decline is climate, which presumably becomes cooler to the north due in part to increased elevation. Greater upriver topographical undulation may also be a factor. Seepage zones that support rare taxa are less likely to form on steep slopes, occurring instead on the lower slopes and bottomlands where the farms, settlements, and roads of this area are concentrated. In addition, the Kintore Hills may act as a geographic barrier to upriver migration, as these noncalcareous hills rise sharply from the edge of the St. John River and prevent bottomland formation. To the south, in the lower St. John River Valley, the absence of calcareous parent material is thought to explain the reduced presence of SJRHF vascular flora, especially the rare taxa, though longer-term human disturbance, dating back to the early 1700s, and substantial flooding by a hydroelectric dam above Fredericton (est. 1968) undoubtedly restrict present-day occurrence as well.

Within-stand floral surveys indicated that rare SJRHF vascular plant taxa were skewed towards moist microsites. The processes driving this distribution pattern are unclear. It may reflect higher moisture levels, though the accumulation of ground water and surface runoff may also concentrate solubilized mineral nutrients at these locations. The prevalence of *Juglans cinerea* and *Tilia americana* in seeps may indicate that vernal understory light intensity is also a factor (e.g., Brewer 1980), as both leaf-out several weeks later than the other deciduous tree species.

Predictive success. The habitat-based search method, driven largely by Ecological Land Classification data, had a success rate of 49% for sites with one or more rare species. This level of predictive success in finding new rare plant stations is considerably higher than that of other studies using similar methods (e.g., 18% by Stahle and Chaney 1994; 10% by Sperduto and Congalton 1996; 4% by Nekola 1994), likely reflecting the strong association between the selected habitat features and the occurrence of SJRHF floral elements. Previous survey limitations may have also contributed to the high success. Given that most sites with rare flora were on the west side of the St. John River Valley, this procedure should also be attempted in Maine (two sites abutted the international boundary). Even if the deciduous forests of Aroostook County have been more intensively disturbed, these results demonstrate that very small and highly isolated stands can contain rare SJRHF elements.

Conservation implications. One of the underlying assumptions of this study was that stand remnants with rare SJRHF taxa would show no evidence of human disturbance. It was thought that these stands served as refuges from the perturbations affecting other forested areas, an assertion supported by the fact that rare taxa were previously unknown from the regenerating forests of the region. Results from this survey, however, revealed that this assertion was overly simplistic. Only 4% of the "mature" and "over-mature" surveyed stands lacked evidence of past selective cutting, such as stumps or old skid trails. In addition, 13 "immature" tolerant hardwood stands within the Meduxnekeag River watershed contained rare species. Although no rare SJRHF vascular plants are known from regenerating stands with coniferous and intolerant hardwood canopies (i.e., old field), the occurrence of rare herbs in previously disturbed tolerant hardwood sites implies that these taxa can withstand some stand perturbation. This is consistent with Keddy and Drummond (1996) who speculated that deciduous forest understory flora may be insensitive to certain forms of cutting. Post-harvest herb studies by Reader (1987) and Metzger and Shultz (1981) both demonstrated little deciduous forest herb loss following selective logging.

It is beyond the scope of this paper to determine the relationship between stand disturbance and herb persistence. Conclusions are limited, in part, due to the absence of comparative surveys in "immature" deciduous stands in the region. It is unknown if "immature" stands outside of the Meduxnekeag River Valley watershed also support rare floral assemblages, or whether this is a localized phenomenon. In addition, absence of detailed stand measurements prevents determining if the photo-interpreted distinction between "mature"/"overmature" and "immature" stands is ecologically meaningful. The key feature used to distinguish "immature" stands from older ones is canopy architecture, yet differences in canopy appearance could reflect site differences rather than stand history in some cases. Also, canopy architecture may not be a true reflection of stand age if long-term selective high-grading has occurred. Persistent cutting of older trees would prevent the development of structural features typical of late-seral deciduous forest (e.g., large-sized individuals, snags and large canopy gaps created by mature tree death) but may not affect the persistence of SJRHF understory vegetation due to the continued retention of large portions of the canopy.

Despite these explanatory limitations, it is clear that present-day rare SJRHF taxa can occur in stands that have been disturbed to some degree. This raises two questions regarding the long-term conservation status of SJRHF assemblages: 1) does the occurrence of rare taxa in disturbed sites reflect post-disturbance colonization, or the persistence of pre-disturbance populations? and 2) for rare herbs that apparently tolerate some disturbance, which harvest schemes are least detrimental to their persistence?

Determining the origins of SRJHF ground flora within hardwood remnants requires testing the dispersal and establishment capabilities of these taxa. Although such information is locally unavailable, studies in deciduous forests of the eastern United States suggest that woodland herb establishment in regenerating stands is infrequent, or extremely slow on the order of centuries, due to poor dispersal ability (Duffy and Meier 1992; Matlack 1994). Post-disturbance soil fertility changes (e.g., Holmes and Zak 1999) may also be a factor. If SJRHF understory species are not re-establishing, most, if not all, of the present-day sites must be remnants of the pre-colonial forest that escaped deforestation in the 19th century and then survived subsequent stand disturbances. This implies that ongoing land clearance and clearcutting are incrementally reducing the number of SJRHF site occurrences, and that protection of the remaining areas becomes critical for SJRHF persistence within New Brunswick and Maine. Site loss would be most detrimental to rare taxa that are currently known from only a few locations. As a result, in addition to protection, reintroduction programs may be needed for these taxa to increase the number of occurrences within the region, and to bolster within-stand populations. A demographic analysis of *Asarum canadense* (Damman and Cain 1998) suggested that populations below 25 individuals were not viable under optimal environmental conditions. If this minimum viable population level is assumed for all SJRHF species, then several may presently be at risk (*Cardamine concatenata, Sanicula odorata, Dryopteris clintoniana* and associated hybrids, and *Galearis spectabilis*).

Observations from this study suggest that there may be select-cut scenarios not detrimental to rare SJRHF flora. Unfortunately, there are insufficient data to quantify disturbance thresholds above which understory herbs are adversely affected. Presumably, the overall effect of disturbance on SJRHF species depends on the intensity, frequency, and extent of intrusions. Factors such as type of harvest (extraction by horse versus skidder), harvest season (snow cover could protect some species), extent of canopy removal, location (seepage zones), and presence of weedy invasive species in the seedbank all influence post-harvest ground flora composition. If the effect of various cutting intensities could be determined, however, it may be possible to modify management approaches so that SJRHF understory species are maintained. At sites where reserve formation is not an option due to landowner reluctance, implementing such strategies may be the only viable conservation alternative. Given the increased pressures for conversion of forests to agricultural fields within western New Brunswick, maintaining working forests may serve as an effective means of maintaining these stands in lieu of full protection.

ACKNOWLEDGMENTS. This project was made possible by the contributions of Gart Bishop and Bruce Bagnell (B & B Botanical), and Samantha Hines. Vince Zelazny and Hilary Veen conducted all GIS work and offered much support. Jim Goltz, Hal Hinds, Stephen Clayden, Judy Loo, Margo Sheppard, Mark Colpitts, Ken Vasiliauskas, Amy McComb, George Peabody, and Jessie Davies provided invaluable guidance and assistance. Comments from two anonymous reviewers greatly improved the manuscript. *Dryopteris* hybrids were identified by Jim Goltz and Don

Britton. Funding was provided by The New Brunswick Environmental Trust Fund, The EJLB Foundation, The T. R. Meighen Foundation, Mountain Equipment Co-op, The World Wildlife Fund, The McCain Foundation, and The Shell Environmental Fund. The Canadian Forest Service-Atlantic Region, New Brunswick Department of Natural Resources and Energy, and The Nature Trust of New Brunswick provided significant in-kind contributions.

LITERATURE CITED

ANDERSON, R. S., R. B. DAVIS, N. G. MILLER, AND R. STUCKENRATH. 1986. History of late- and post-glacial vegetation and disturbance around Upper South Branch Pond, northern Maine. Canad. J. Bot. 64: 1977–1986.

BAILEY, J. W. 1894. The St. John River in Maine, Quebec, and New Brunswick. L. P. Fisher Library, Woodstock, NB, Canada.

BIERZYCHUDEK, P. 1982. Life histories and demography of shade-tolerant forest herbs: A review. New Phytol. 90: 757–776.

BOUSFIELD, E. L. AND M. L. H. THOMAS. 1975. Postglacial changes in distribution of littoral marine invertebrates in the Canadian Atlantic region. Proc. Nova Scotian Inst. Sci. 27: 47–60.

BRAUN, E. L. 1950. Deciduous Forests of Eastern North America. The Blakiston Co., Toronto, Canada.

BREWER, R. 1980. A half-century of changes in the herb layer of a climax deciduous forest in Michigan. J. Ecol. 68: 823–832.

BURNS, R. M. AND B. H. HONKALA. 1990. Silvics of North America, Vol. 2. Hardwoods. Agriculture Handbook 654, U.S. Forest Serv., Washington, DC.

CAIN, M. L., H. DAMMAN, AND A. MUIR. 1998. Seed dispersal and the Holocene migration of woodland herbs. Ecol. Monogr. 68: 325–347.

CAMPBELL, C. S. ET AL. 1995. Checklist of Vascular Plants of Maine. Josselyn Bot. Soc. Maine, Bull. 13. Maine Agric. Forest Exp. Sta., Univ. Maine, Orono, ME.

COLPITTS, M. C., S. H. FAHMY, J. E. MACDOUGALL, T. T. M. NG, B. G. MCINNIS, AND V. F. ZELAZNY. 1995. Forest Soils of New Brunswick. New Brunswick Dept. of Nat. Resources & Energy, Fredericton, NB, Canada.

COONEY, R. 1832. A Compendious History of the Northern Part of the Province of New Brunswick and of the District of Gaspé in Lower Canada. Joseph Howe, Halifax, NS, Canada.

CRONON, W. 1983. Changes in the Land: Indians, Colonists, and the Ecology of New England. Hill and Wang, New York.

DAMMAN, H. AND M. L. CAIN. 1998. Population growth and viability analyses of the clonal woodland herb, *Asarum canadense*. J. Ecol. 86: 13–26.

DAVIS, M. B. 1976. Pleistocene biogeography of temperate deciduous forests. Geosci. & Man 13: 13–26.

———, R. W. SPEAR, AND L. C. K. SHANE. 1980. Holocene climate of New England. Quatern. Res. 14: 240–250.

Deevey, E. S. 1951. Late-glacial and postglacial pollen diagrams from Maine. Amer. J. Sci. 249: 177–207.

Duffy, D. C. and A. J. Meier. 1992. Do Appalachian herbaceous understories ever recover from clearcutting? Conservation Biol. 6: 196–201.

Eastman, L. M. 1981. Rare Vascular Plants of Maine. Maine Crit. Areas Program, State Planning Office, Augusta, ME.

Erskine, D. S. 1985. The Plants of Prince Edward Island with New Records, Nomenclatural Changes, and Corrections and Deletions. Publ. No. 1798. Research Branch, Agric. Canada, Ottawa, ON, Canada.

Fernald, M. L. 1921. The Gray Herbarium expedition to Nova Scotia, 1920. Rhodora 23: 89–111, 130–152, 153–171, 184–195, 223–246, 257–278, 284–301.

———. 1922. Notes on the flora of western Nova Scotia 1921. Rhodora 24: 157–164, 165–180, 201–208.

———. 1950. Gray's Manual of Botany. 8th ed. American Book Co., New York.

——— and K. M. Wiegand. 1910. A summer's botanizing in eastern Maine and western New Brunswick. Rhodora 12: 101–121, 133–141.

Fernow, B. E., C. D. Howe, and J. H. White. 1912. Forest conditions of Nova Scotia. Commission of Conservation, Ottawa, ON, Canada.

Foster, D. S., G. Motzkin, and B. Slater. 1998. Land use history as long-term broad-scale disturbance: Regional forest dynamics in central New England. Ecosystems 1: 96–119.

Fowler, J. 1885. Preliminary list of the plants of New Brunswick. Bull. Nat. Hist. Soc. New Brunswick 4: 8–84.

Ganong, W. F. 1899. Indian routes of travel in New Brunswick. Trans. Roy. Soc. Canada, New Brunswick Museum, St. John, NB, Canada.

Gawler, S. C., J. J. Albright, P. D. Vickery, and F. C. Smith. 1996. Biological Diversity in Maine: An Assessment of Status and Trends in the Terrestrial and Freshwater Landscape. Maine Nat. Areas Program, Dept. Conservation, Augusta, ME.

Goodale, G. L. 1861. Preliminary Report upon the Natural History and Geology of the State of Maine. Maine Board Agric., Augusta, ME.

———. 1862. Second Annual Report upon the Natural History and Geology of the State of Maine. Maine Board Agric., Augusta, ME.

Green, D. G. 1987. Pollen evidence for the postglacial origins of Nova Scotia's forests. Canad. J. Bot. 65: 1163–1179.

Haines, A. and T. F. Vining. 1998. Flora of Maine. V. F. Thomas Co., Bar Harbor, ME.

Halliday, W. E. D. 1937. A Forest Classification for Canada. Forest Res. Div. Bull. No. 89, Canada Dept. Resources & Development, Ottawa, ON, Canada.

Hawley, R. C. and A. F. Hawes. 1912. Forestry in New England: A Handbook of Eastern Forest Management. John Wiley and Sons, New York.

Hay, G. U. 1883. Botany of the upper St. John. Bull. Nat. Hist. Soc. New Brunswick 2: 21–37.

———. 1896. The Restigouche—with notes especially on its flora. Bull. Nat. Hist. Soc. New Brunswick 14: 12–35.

———. 1901. Report of the committee on botany. Bull. Nat. Hist. Soc. New Brunswick 19: 350–353.

———, R. Chalmers, and J. Vroom. 1882. List of plants for New Brunswick. Bull. Nat. Hist. Soc. New Brunswick 1: 17–22.

———, J. Vroom, and R. Chalmers. 1884. Additional list of plants for New Brunswick. Bull. Nat. Hist. Soc. New Brunswick 3: 30–36.

Hinds, H. R. 1980. Annotated checklist of the vascular plants of Carleton County, New Brunswick. J. New Brunswick Mus., pp. 120–144.

———. 1983. The Rare Vascular Flora of New Brunswick. Syllogeus No. 50, Canad. Mus. Nature, Ottawa, ON, Canada.

———. 1986. The Flora of New Brunswick. Primrose Press, Fredericton, NB, Canada.

Holmes, W. E. and D. R. Zak. 1999. Soil microbial control of nitrogen loss following clearcut harvest in northern hardwood ecosystems. Ecol. Applic. 9: 202–215.

Keddy, P. A. and C. G. Drummond. 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. Ecol. Applic. 6: 748–762.

Kellman, M. C. 1980. Plant Geography. St. Martin's Press, New York.

Kranck, K. 1972. Geomorphological development and post-Pleistocene sea level changes, Northumberland Strait, Maritime Provinces. Canad. J. Earth Sci. 9: 835–844.

Loucks, O. L. 1961. A forest classification for the Maritime Provinces. Proc. Nova Scotian Inst. Sci. 25: 85–167.

Lutz, S. 1997. Pre-European settlement and present forest composition in King's County, New Brunswick, Canada. M.S. thesis, Dept. Forestry, Univ. New Brunswick, Fredericton, NB, Canada.

MacDougall, A. S. and J. A. Loo. 1998. Natural History of the Saint John River Valley Hardwood Forest of Western New Brunswick and Northeastern Maine. Inform. Rep. M-X-204E, Canadian Forest Service—Atlantic Forestry Centre, Fredericton, NB, Canada.

———, ———, S. Clayden, J. Goltz, and H. R. Hinds. 1998. Defining conservation priorities for plant taxa in southeastern New Brunswick, Canada using herbarium records. Biol. Conservation 86: 325–338.

Matlack, G. R. 1994. Plant species migration in a mixed-history forest landscape in eastern North America. Ecology 75: 1491–1502.

———. 1997. Four centuries of forest clearance and regeneration in the hinterland of a large city. J. Biogeogr. 24: 281–295.

McMahon, J. S. 1990. The biophysical regions of Maine: Patterns in the landscape and vegetation. M.S. thesis, Dept. Botany, Univ. Maine, Orono, ME.

Meier, A. J., S. P. Bratton, and D. C. Duffy. 1995. Possible ecological mechanisms for loss of vernal-herb diversity in logged eastern deciduous forests. Ecol. Applic. 5: 935–946.

Metzger, F. and J. Schultz. 1981. Spring ground layer vegetation 50 years after harvesting in northern hardwood forests. Amer. Midl. Naturalist 105: 44–50.

Michaux, F. A. 1808. [translated by J. J. Smith, 1857] The North American

Sylva: Or, a Description of the Forest Trees of the United States, Canada, and Nova Scotia. D. Rice and A. N. Hart, Philadelphia, PA.

MILLETTE, J. F. G. AND K. K. LANGMAID. 1964. Soil survey of the Andover-Plaster Rock Area, New Brunswick. 5th Rep. New Brunswick Soil Surv., Canada Dept. Agric., Ottawa, ON, Canada.

MOTT, R. J. 1975a. Palynological studies of lake sediment profiles from southwestern New Brunswick. Canad. J. Earth Sci. 12: 273–288.

———. 1975b. Postglacial history and environments of southwestern New Brunswick. Proc. Nova Scotian Inst. Sci. 27: 67–82.

NEKOLA, J. C. 1994. The environment and vascular flora of northeastern Iowa fen communities. Rhodora 96: 121–169.

NEW BRUNSWICK COMMITTEE ON ENDANGERED SPECIES. 1995. Species-at-risk Designations in the Province of New Brunswick. New Brunswick Dept. Nat. Resources & Energy, Fredericton, NB, Canada.

NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES AND ENERGY. 1996. An Ecological Land Classification System for New Brunswick. Draft rep. New Brunswick Dept. Nat. Resources & Energy, Fredericton, NB, Canada.

NICHOLLS, G. E. 1918. The vegetation of northern Cape Breton Island, Nova Scotia. Proc. Conn. Acad. Arts Sci. 22: 249–267.

PERLEY, M. 1847. Report on the forest trees of New Brunswick. Simmonds Colonial Mag. 11: 142–155, 314–429.

PRENTICE, I. C., P. J. BARTLEIN, AND T. WEBB III. 1991. Vegetation and climate change in eastern North America since the last glacial maximum. Ecology 72: 2038–2056.

PRONYCH, G. AND A. WILSON. 1993. Atlas of the Rare Vascular Plants of Nova Scotia, Vol. 1. Nova Scotia Museum of Natural History, Halifax, NS, Canada.

RAUP, H. M. 1937. Recent changes of climate and vegetation in southern New England and adjacent New York. J. Arnold Arbor. 18: 79–117.

READER, R. J. 1987. Loss of species from deciduous forest understorey immediately following selective tree harvesting. Biol. Conservation 42: 231–244.

ROBINSON, C. B. 1903. Early intervale flora of eastern Nova Scotia. Proc. & Trans. Nova Scotian Inst. Sci. 10: 502–506.

ROUSSEAU, C. 1974. Geographie Floristique du Quebec–Labrador: Distribution des Principales Espèces Vasculaires. Les Presses de l'Université Laval, Quebec, Canada.

ST. JOHN, H. 1929. Plants of the headwaters of the St. John River, Maine. Res. Stud. State Coll. Wash. 1: 28–58.

SPECK, F. G. AND R. W. DEXTER. 1952. Utilization of animals and plants by the Malecite Indians of New Brunswick. J. Wash. Acad. Sci. 42: 1–7.

SPERDUTO, M. B. AND R. G. CONGALTON 1996. Predicting rare orchid (small whorled pogonia) habitat using GIS. Photogrammetric Engineering and Remote Sensing 62: 1269–1279.

STAHLE, D. W. AND P. L. CHANEY. 1994. A predictive model for the location of ancient forests. Nat. Areas J. 14: 151–158.

WHITNEY G. G. AND D. R. FOSTER. 1988. Overstorey composition and age as determinants of the understorey flora of woods of central New England. J. Ecol. 76: 867–876.

ZELAZNY, V., H. VEEN, AND M. COLPITTS. 1997. Ecological Land Classification for New Brunswick: Ecoregion, Ecodistrict, and Ecosite Levels. Draft rep. New Brunswick Dept. Nat. Resources & Energy, Fredericton, NB, Canada.

ZINCK, M. 1998. Roland's Flora of Nova Scotia. Nimbus Publishing, Halifax, NS, Canada.